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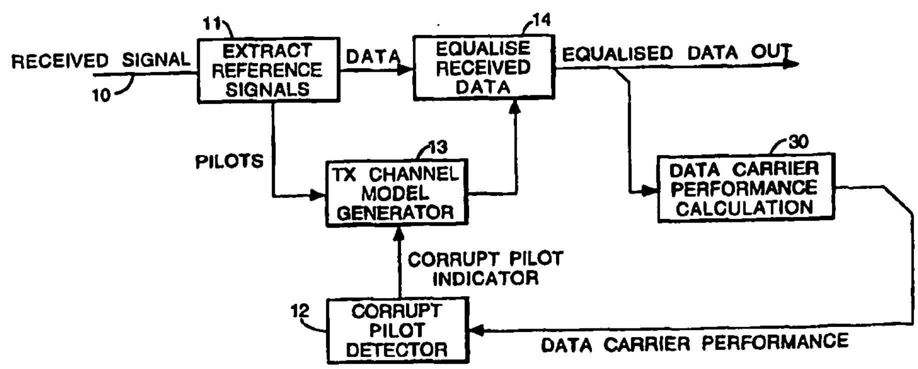

(57) Abstract

This invention relates generally to transmitting and receiving frequency division multiplex signals and, more precisely, to a method and apparatus for transmitting and receiving orthogonal frequency division multiplex (OFDM) signals. OFDM signals may include both data carriers and reference carriers (or pilots). The pilot signals are transmitted at known positions with a known phase and amplitude, however distortions in the transmission channel can adversely affect the data received at a receiver. Pilots are used by a receiver to correct the data carriers which may have been affected by distortion or interference in the transmission channel. However, if a pilot signal is corrupted during transmission this can lead to the data carriers being erroneously corrected. The present invention seeks to provide a method and apparatus for receiving a frequency division multiplex signal in which the effect of corrupt pilot signals can be monitored and reduced.

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Method and Apparatus for Receiving Frequency Division Multiplex Signals.

The present invention relates to a method and apparatus for receiving frequency division multiplex signals at a receiver and is particularly adapted to receiving orthogonal frequency division multiplex (OFDM) signals and discrete multitone (DMT) signals. OFDM signals include data carriers and reference carriers. The reference carriers are in the form of a sequence of pilot signals which are distributed in frequency and in time and are transmitted with a pattern of values known to the receiver. At the receiver the pilot signals are used to calculate a reference model of the channel and the data carriers are modified by reference to this model to compensate for channel distortions. This process is known as channel equalisation.

There are certain types of interference that are extremely localised in time or in frequency. At best, this interference will result in the destruction of a carrier modulated with data and that data will therefore be lost. However, if a pilot signal is corrupted by the interference the effect is spread both in time and across several carriers, causing the channel model to be inaccurate in the region surrounding the interference. This results in sub-optimal equalisation of the carrier signals that are not directly affected by the interference and unnecessary errors in the received data.

The present invention seeks to provide a method and apparatus for receiving at a receiver a frequency division multiplex signal in which the effect of corrupt pilot signals can be monitored and reduced.

According to the present invention there is provided a method of receiving a frequency division multiplex signal including data carriers and reference signals, the method including performing the steps of extracting data carriers and reference signals from the received signal, equalising the data carriers by means of the reference signals and comparing the performance of one or

more data carriers when a selection of one or more reference signals is used for carrier equalisation with the performance of the or each of the data carriers when a different selection of the reference signals is used for carrier equalisation.

Further according to the present invention there is provided apparatus for receiving a frequency division multiplex signal including data carriers and reference signals, the apparatus comprising an extractor to extract data carriers and reference signals from the received signal, an equaliser to equalise the data carriers by means of the reference signals, and a comparator operable to compare the performance of one or more data carriers when a selection is made of one or more reference signals for carrier equalisation with the performance of the or each of the data carriers when a different selection of the reference signals is used for carrier equalisation.

The invention will now be described, by way of example, with reference to the accompanying drawings in which ;

Figure 1 shows a block diagram of an OFDM receiver according to the present invention,

Figure 2 is one example of the pattern of data carriers and pilot signals in an OFDM signal to be received by the receiver of Figure 1,

Figure 3 shows details of a filter in a frequency interpolation section of the receiver of Figure 1,

Figure 4 shows a modification to the filter of Figure 3,

Figure 5 shows the frequency interpolation section within block 13 of the receiver of Figure 1, and

Figure 6 shows details of the corrupt pilot detector of Figure 1.

Referring to Figures 1 and 2, there is shown a receiver to which an OFDM signal is transmitted and received at an input lead 10. The OFDM signal includes a succession of symbols which are indicated in Figure 2. Each symbol includes a set of frequency spaced data carriers indicated as x in Figure 2 together with scattered pilots (or reference carrier signals), indicated as O, which are distributed amongst the data carriers. In addition the symbols each have continuous pilots (or reference carrier signals) O one of which is shown at the right hand margin of Figure 2.

The scattered pilots are distributed throughout the data carriers in a predetermined pattern and have values which are known at the receiver. The receiver has a circuit 11 to extract the data to be passed on to a block 14 at which the data carriers are modified to compensate for distortions in the transmission channel. The pilot or reference signals are also extracted at the circuit 11 and passed to a block 13 which models the transmission channel. The block 13 uses the pilots to model the transmission channel and supplies signals to the block 14 which equalises the data received from the circuit 11.

In the event of interference which is effective to corrupt a pilot signal, the channel model assumed by the block 13 will be inaccurate in the region surrounding the interferer. It is necessary therefore to take steps to mitigate this effect and the detector 12 is provided to detect a corrupt pilot and to modify the model by issuing signals to the block 13 in a manner which will be described in greater detail by reference to Figures 3 to 6.

The Transmission Channel Model Generator block 13 in Figure 1 comprises two stages. The first stage takes the form of an interpolation filter operating in the time direction, which takes the incoming scattered pilot values and produces for each carrier that contains scattered pilot cells, a value on every symbol. This can be done by a variety of methods including sample and hold,

Finite Impulse Response (FIR) filtering and Infinite Impulse Response (IIR) filtering of the incoming pilot values, one of which is described in our co-pending United Kingdom Patent Application Number: GB 9700947.6.

The second stage consists of an interpolation filter operating in the frequency direction.

Figure 3 shows the basic operation of the frequency interpolator which takes the form of a finite impulse response filter including a data register 22 to receive the time interpolated pilots. The missing positions between the pilots (i.e. those containing modulated data) are filled with zeros so that the pilot carriers fall on every third tap of the filter and the intervening taps have no effect on the result. Nine filter taps are shown each including a multiplier supplying a summing circuit 23.

The taps have respective filter coefficients C0 to C8. After each output from the summing circuit 23, the input to the shift register 22 is shifted by one tap so that there are effectively 3 sets of filter coefficients that are used sequentially and the filter effectively operates in 3 phases to produce corresponding filtered signals for modelling the transmission channel.

The filter shown in Figure 3 could alternatively be implemented by a polyphase filter as shown in Figure 4. In this case the time interpolated pilots are supplied to a data register 26 and the multiplier of each tap is supplied with multiple coefficients through multiplexers 100,101 and 102.

The three multiplexers operate in three phases so that a shift in phase is executed after each output from the summing circuit 23. Thus the first multiplexer 100 supplies sequentially the coefficients C0 - C2, the second multiplexer 101 supplies sequentially the coefficients C3 - C5 and the third multiplexer 102 supplies sequentially the coefficients C6-C8.

The corrupt pilot detector 12 of Figure 1 is employed to detect whether pilots have been corrupted and mitigates the effect of corrupted pilots by automatically selecting an alternate set of replacement filter coefficients for the interpolation filters.

The process is now described with reference to the frequency interpolation filter of Figure 5.

Referring now to Figure 5, the corrupt pilot detector supplies to a terminal 30 a binary indication for each pilot whether the pilot is detected as good or as bad. Thus a good pilot may be represented by a binary value of 0 and a bad pilot may be represented by a binary value of 1. The binary values are passed into a data register having register positions 31, 32 and 33 in the example shown in Figure 5.

A phase counter 34 is used to supply an indication of which of the 3 phases is current as already explained in relation to the filters of Figures 3 and 4.

The phase indication is supplied to a combinatorial logic circuit 35 which also receives the good/bad binary values from the register positions 31, 32 and 33. The combinatorial logic 35 generates phase and address control signals which select addresses in three read only memories 36, 37 and 38 which correspond to the three multiplexers 100, 101 and 102 of the polyphase filter of Figure 4. The read only memories 36, 37 and 38 supply filter coefficients to respective multipliers 39, 40 and 41 which form part of the taps of a finite impulse response filter equivalent to the filter of Figure 4. The time interpolated pilots to be filtered are supplied to an input terminal 42 and the filter taps supply a summing circuit 43 the output of which constitutes the filtered signal for modelling the transmission channel.

In the event of a corrupt pilot being detected, the corresponding binary value of 1 is entered at the terminal 30 and the combinatorial logic 35 will respond

by addressing the read only memories 36, 37 and 38 to select filter coefficients which limit the effect of the corrupted pilot while maintaining the overall gain and frequency response of the interpolator. As an alternative, the combinatorial logic can be used to replace the corrupted pilot value with zero and the filter output scaled to maintain constant gain.

Both adaptive filtering methods reduce the input sampling rate in the vicinity of the corrupted pilot. This is not serious at the edges of the filter where the coefficients are small, but will have a larger effect on the global filter frequency response near the centre. The first method has the advantage that the replacement coefficients need not be scaled versions of the original global filter coefficients and it may be possible to reduce the effect of local aliasing. The second method requires the storage of less data, because a simple gain correction factor is required in place of a whole set of filter coefficients.

The adaptive frequency interpolation technique described above, relies on the ability to detect the presence of corrupt pilot carriers within the multiplex signal.

The presence of corrupt pilot signals is determined by the improvement in the measured performance of data carriers in the region of a corrupt pilot carrier, when that pilot is not used by the frequency interpolator. This guarantees that adaptive frequency interpolation is applied and only applied when it provides an improvement in receiver performance as measured on the data carriers. This is clearly a far better solution than methods previously considered, since it provides closed loop control of the adaptive interpolator.

Figure 1 shows how the performance feedback detection of corrupted pilots is incorporated into the receiver and Figure 6 shows in detail the components of the corrupt pilot detector (12) of Figure 1.

The carrier performance values are calculated in block 30 of Figure 1. There are many different methods for determining the carrier performance values as will be understood by those skilled in the art.

The integrity of each of the 569 carriers containing either scattered or continuous pilot signals is evaluated independently. The process is now described with reference to the block diagram shown in Figure 6.

Block 131 integrates the data carrier performance values in the region of the pilot under test, to form a measure of the receiver performance in the region of that pilot. Two values for each pilot position are calculated, one value for the case when the pilot value is included in the frequency interpolation calculation and one when the pilot value is omitted from the frequency interpolation calculation. In the receiver described in Figure 6 these calculations are performed sequentially and the first integration result of each pair is stored in block 132 until the second has been completed, whereupon block 133 performs a comparison between the two integrals in order to evaluate the best operating mode under the prevailing conditions. This operation is then repeated for the 569 carriers containing either scattered or continuous pilot signals and the results are stored in the pilot status store 134 which determines when a pilot carrier is signalled as corrupt at the input to the frequency interpolator.

This strategy will automatically trade off any loss in interpolation accuracy introduced by adaptive frequency interpolation and the improvement gained by omitting corrupted pilots.

CLAIMS

1. A method of receiving a frequency division multiplex signal including data carriers and reference signals, the method including performing the steps of extracting data carriers and reference signals from the received signal, equalising the data carriers by means of the reference signals and comparing the performance of one or more data carriers when a selection of one or more reference signals is used for carrier equalisation with the performance of the or each of the data carriers when a different selection of the reference signals is used for carrier equalisation.

2. A method as claimed in claim 1, wherein the comparing step is performed to allow a corrupt pilot to be detected.

3. A method as claimed in claim 2, wherein the said comparing step is repeated for a plurality of different selections of the reference signals.

4. A method as claimed in claim 1, 2 or 3 including the further step of filtering the reference signals to derive reference values which are interpolated in frequency.

5. A method as claimed in claim 4 further comprising filtering the reference signals by an adaptive filtering step.

6. A method as claimed in claim 1, 2, 3, 4 or 5 including the further step of time interpolating the reference signals before the step of equalising the data carriers by means of the reference signals.

7. Apparatus for receiving a frequency division multiplex signal including data carriers and reference signals, the receiver comprising an extractor to extract data carriers and reference signals from the

received signal, an equaliser to equalise the data carriers by means of the reference signals, and a comparator operable to compare the performance of one or more data carriers when a selection is made of one or more reference signals for carrier equalisation with the performance of the or each of the data carriers when a different selection of the reference signals is used for carrier equalisation.

8. Apparatus as claimed in claim 7, wherein the performance comparator is adapted to identify whether a selected reference signal is corrupt.

9. Apparatus as claimed in claim 7 or 8, wherein the performance comparator means is adapted to repeat the performance comparison for each of a succession of selections of the reference signals.

10. Apparatus as claimed in claim 7, 8 or 9, wherein at least one filter is provided to filter the reference signals to derive reference values which are interpolated in frequency.

11. Apparatus as claimed in any one of claims 7 to 10, wherein a time interpolator is provided to subject the reference signals to time interpolation before supplying the reference signals to the means to equalise the data carriers.

12. Apparatus as claimed in any one of claims 7 to 11, further comprising an estimator for estimating the performance of the data carriers by filtering the instantaneous performance of the or each data carriers.

13. A method of transmitting a frequency division multiplex signal including data carriers and reference signals, which signal is adapted to be recovered by the method of any of claims 1 to 6.

14. Apparatus for transmitting a frequency division multiplex signal including data carriers and references signals, which signal is adapted to be recovered by the method of any of claims 7 to 14.

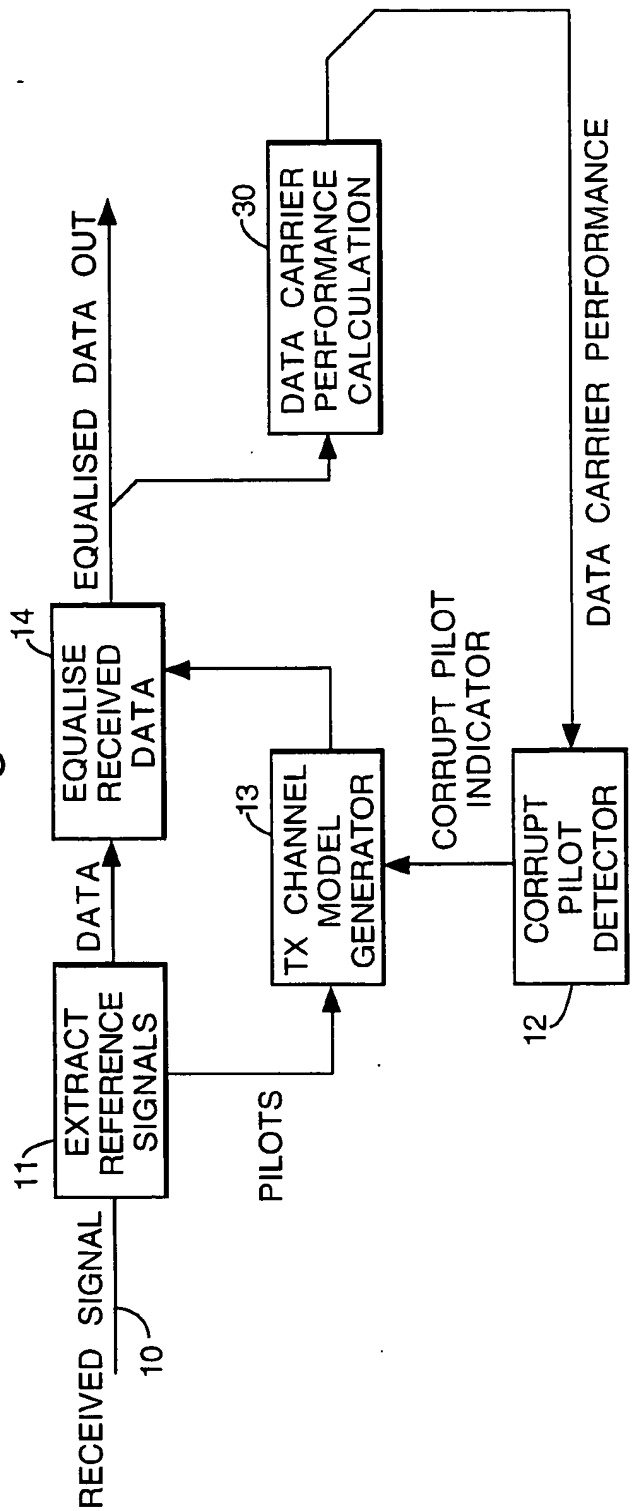

RECEIVED SIGNAL
10
EXTRACT REFERENCE SIGNALS
11
DATA
PILOTS
EQUALISE RECEIVED DATA
14
TX CHANNEL MODEL GENERATOR
13
CORRUPT PILOT INDICATOR
CORRUPT PILOT DETECTOR
12
EQUALISED DATA OUT
DATA CARRIER PERFORMANCE CALCULATION
30
DATA CARRIER PERFORMANCE

Fig.1.

Fig.2.

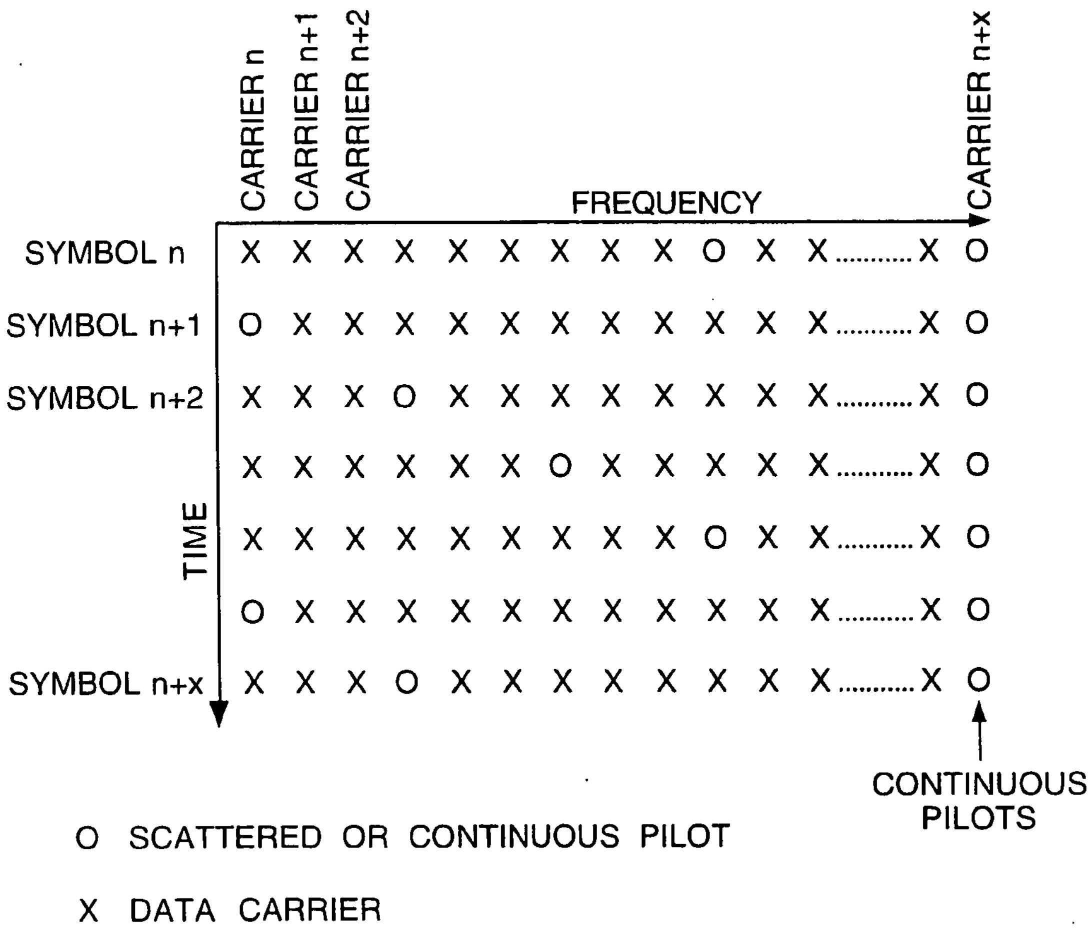

CARRIER n
CARRIER n+1
CARRIER n+2
CARRIER n+x
FREQUENCY
SYMBOL n
SYMBOL n+1
SYMBOL n+2
TIME
SYMBOL n+x
X X X X X X X X X O X X ....X O
O X X X X X X X X X X X ....X O
X X X O X X X X X X X X ....X O
X X X X X X O X X X X X ....X O
X X X X X X X X X O X X ....X O
O X X X X X X X X X X X ....X O
X X X O X X X X X X X X ....X O
CONTINUOUS PILOTS
O SCATTERED OR CONTINUOUS PILOT
X DATA CARRIER

Fig.3.

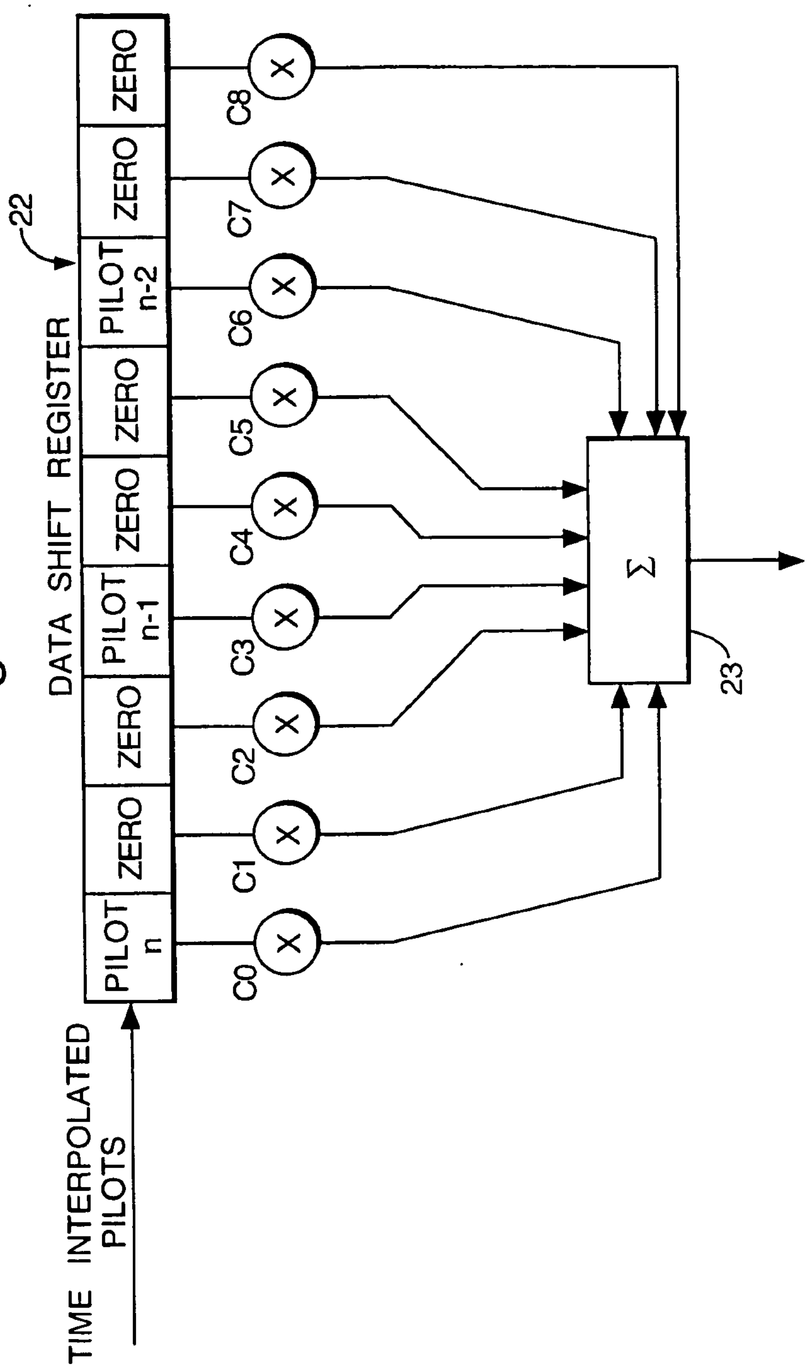

DATA SHIFT REGISTER
22
PILOT n
ZERO
ZERO
PILOT n-1
ZERO
ZERO
PILOT n-2
ZERO
ZERO
C0
C1
C2
C3
C4
C5
C6
C7
C8
Σ
23
TIME INTERPOLATED PILOTS

Fig.4.

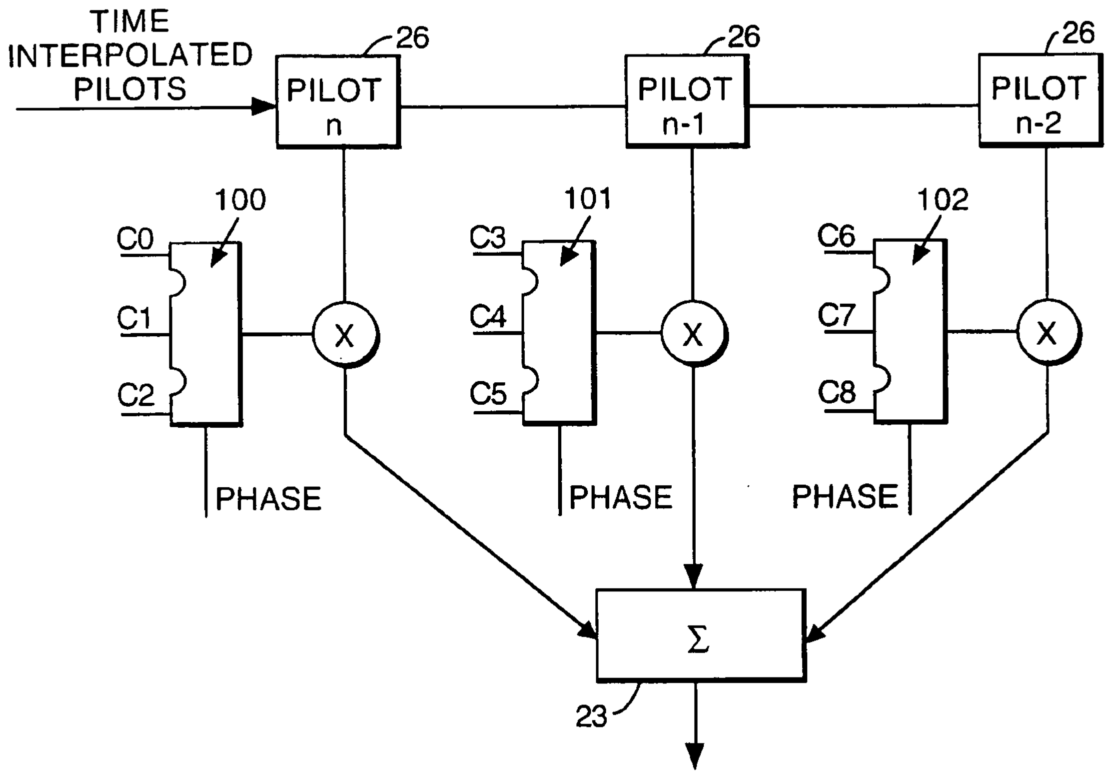

TIME
INTERPOLATED
PILOTS
26
PILOT
n
26
PILOT
n-1
26
PILOT
n-2
100
101
102
C0
C1
C2
C3
C4
C5
C6
C7
C8
X
X
X
PHASE
PHASE
PHASE
Σ
23

Fig.5.

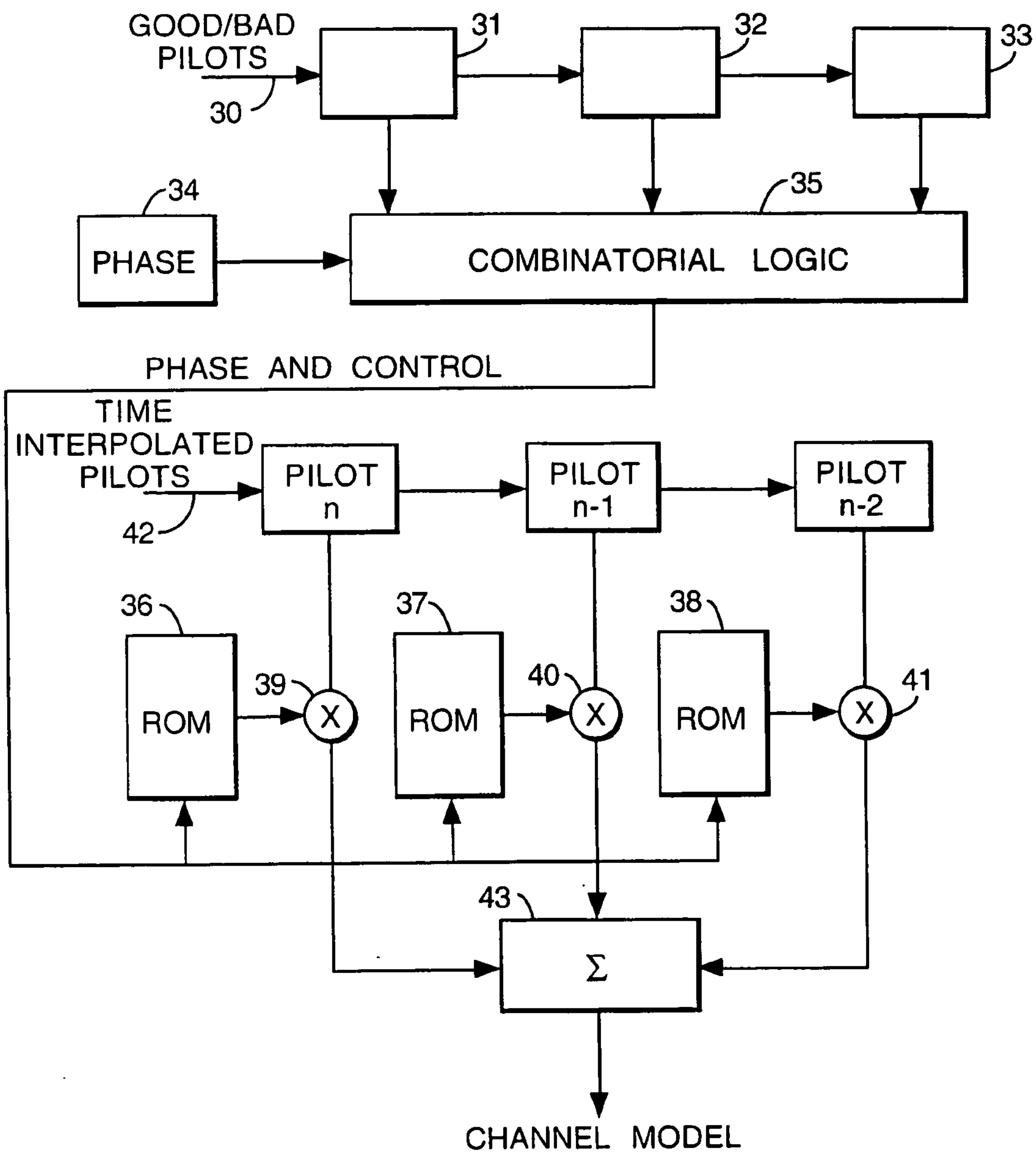
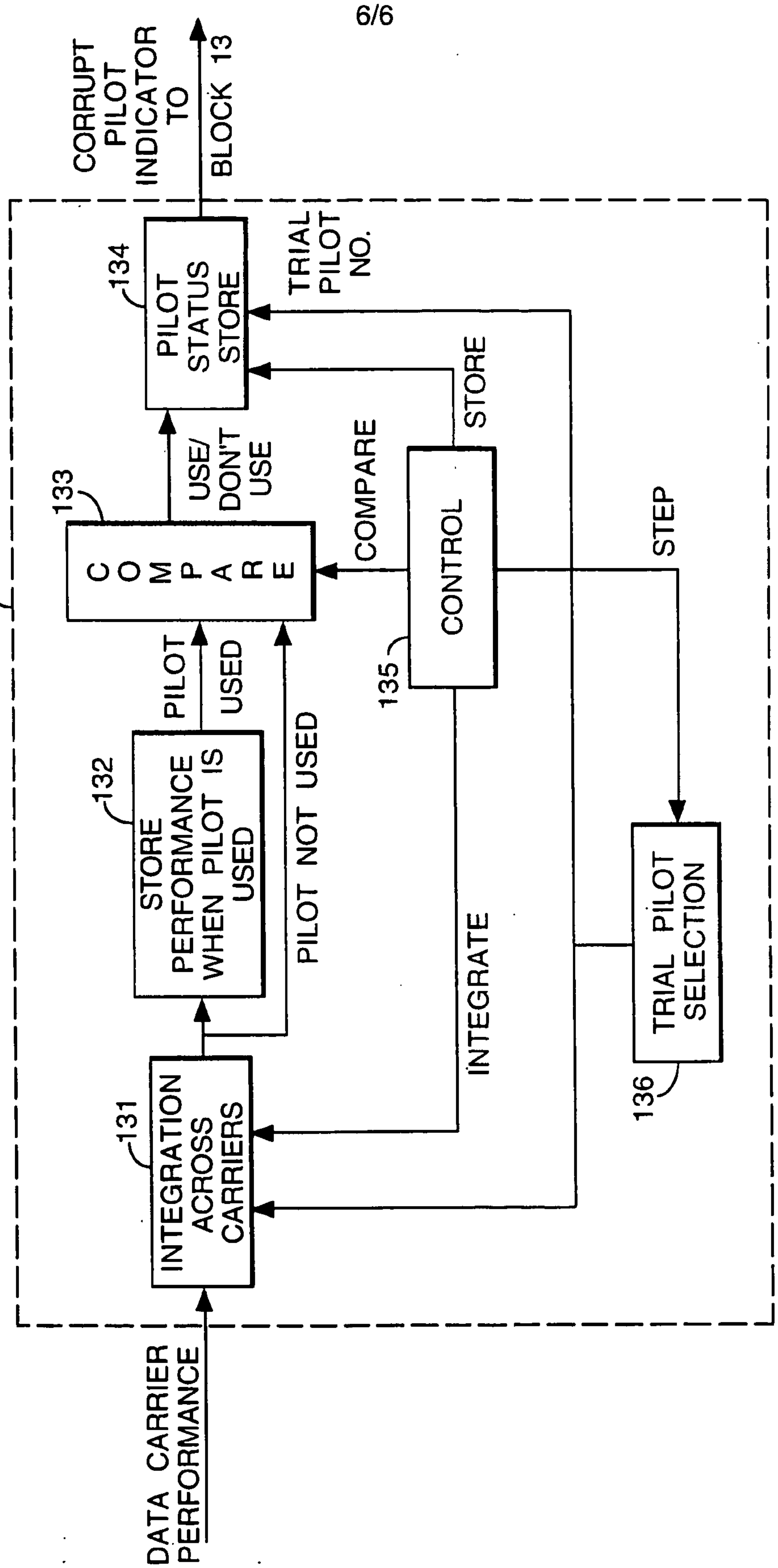

GOOD/BAD
PILOTS
30
31
32
33
34
PHASE
35
COMBINATORIAL LOGIC
PHASE AND CONTROL
TIME
INTERPOLATED
PILOTS
42
PILOT
n
PILOT
n-1
PILOT
n-2
36
37
38
ROM
ROM
ROM
39
40
41
X
X
X
43
Σ
CHANNEL MODEL

Fig.6.


CORRUPT PILOT INDICATOR TO BLOCK 13
12
134
PILOT STATUS STORE
TRIAL PILOT NO.
133
COMPARE
USE/ DON'T USE
STORE
COMPARE
CONTROL
135
STEP
132
STORE PERFORMANCE WHEN PILOT IS USED
PILOT USED
PILOT NOT USED
131
INTEGRATION ACROSS CARRIERS
INTEGRATE
TRIAL PILOT SELECTION
136
DATA CARRIER PERFORMANCE